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DELTA-A SCIENTIFIC AND APPLICATION SATELLITE LAUNCH VEHICLE

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GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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ABSTRACT

The Delta launch vehicle, Model 904 is described for potential users. This new model of Delta is composed of the Long Tank Thor first stage, thrust augmented by 9 Castor II solid propellant motors; the Delta second stage, converted to higher energy storable propellants, uprated by adoption of the Titan Transtage ablative engine and modernized with a strap-down inertial system that replaces independent autopilots/radio guidance systems in the first and second stages; and the elongated TE-364-4 solid propellant third stage motor that evolved from the Surveyor spacecraft retromotor. A brief historical summary of Delta's evolutionary growth and flight record attests to the success of the Delta philosophy of making maximum use of current technology and flight proven components from other space programs. Performance, flight environment, organizational interfaces, spacecraft integration requirements, launch operations and costs are provided.

This new model of Delta is to be available in mid 1971, cost about \$5.0 million dollars and be capable of injecting 4,000 pounds into low earth orbit, 1300 pounds into synchronous transfer orbit, or escaping 900 pounds of payload.

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I. THE EVOLUTION OF DELTA

The evolution of the Delta launch vehicle, shown in Figure 1, reaches back thirteen years when, in 1955, the United States participated in the International Geophysical Year (IGY) and undertook the development of the Vanguard three-stage launch vehicle; in the same year the Air Force initiated the development of the Thor IRBM. With modifications, the Thor became the first stage of Delta; the Vanguard second stage propulsion system, evolved through the Able programs, became the Delta second stage propulsion system; and the Vanguard X-248 third stage solid propellant rocket motor was adapted as the third stage for Delta. The development and integration of these systems and the production of twelve (12) vehicles was started in early 1959 under prime contract to the Douglas Aircraft Company. The initial objective of the Delta program was to provide an interim space launch vehicle capability for the medium-class payloads until more sophisticated vehicles as Scout and Agena, then under development, could be brought to operational status. The development program spanned 18 months. In a little over two years, following the development period, eleven of the twelve vehicles were launched successfully carrying, among others, the first passive communications satellite, Echo I (August 1960), the cooperative NASA/United Kingdom Ariel I (April 1960), the TIROS II through VI series, the first Orbiting Solar Observatory, and the first private industry satellite, AT&T's Telstar I (July 1962). The total development cost, including the twelve vehicles (Model DM-19) and launch support, was approximately $43,000,000, compared to the $40,000,000 estimated at the outset of the program.

Before the development program was complete the number of missions planned for Delta outstripped the interim buy of twelve vehicles, so an order was placed for fourteen additional vehicles. This follow-on buy of Deltas (Models A and B) incorporated lengthened second stage propellant tanks, a higher energy second stage oxidizer, transistorized guidance electronics, and assiduous application of high-reliability semiconductors in flight critical circuits. This model of Delta carried NASA's first active communications satellite, Relay I (December 1962), and the first synchronous satellites, Syncom I and II (February and July 1963).

The next production order of Deltas (Models C and D) in 1963 brought the adaption of the USAF developed improved Thor booster with thrust augmentation provided by three strap-on solid propellant motors and the adaption of the Scout developed X-258 to replace the X-248 third stage motor. The first thrust augmented Delta (TAD) carried Syncom III (August 1964), the first equatorial

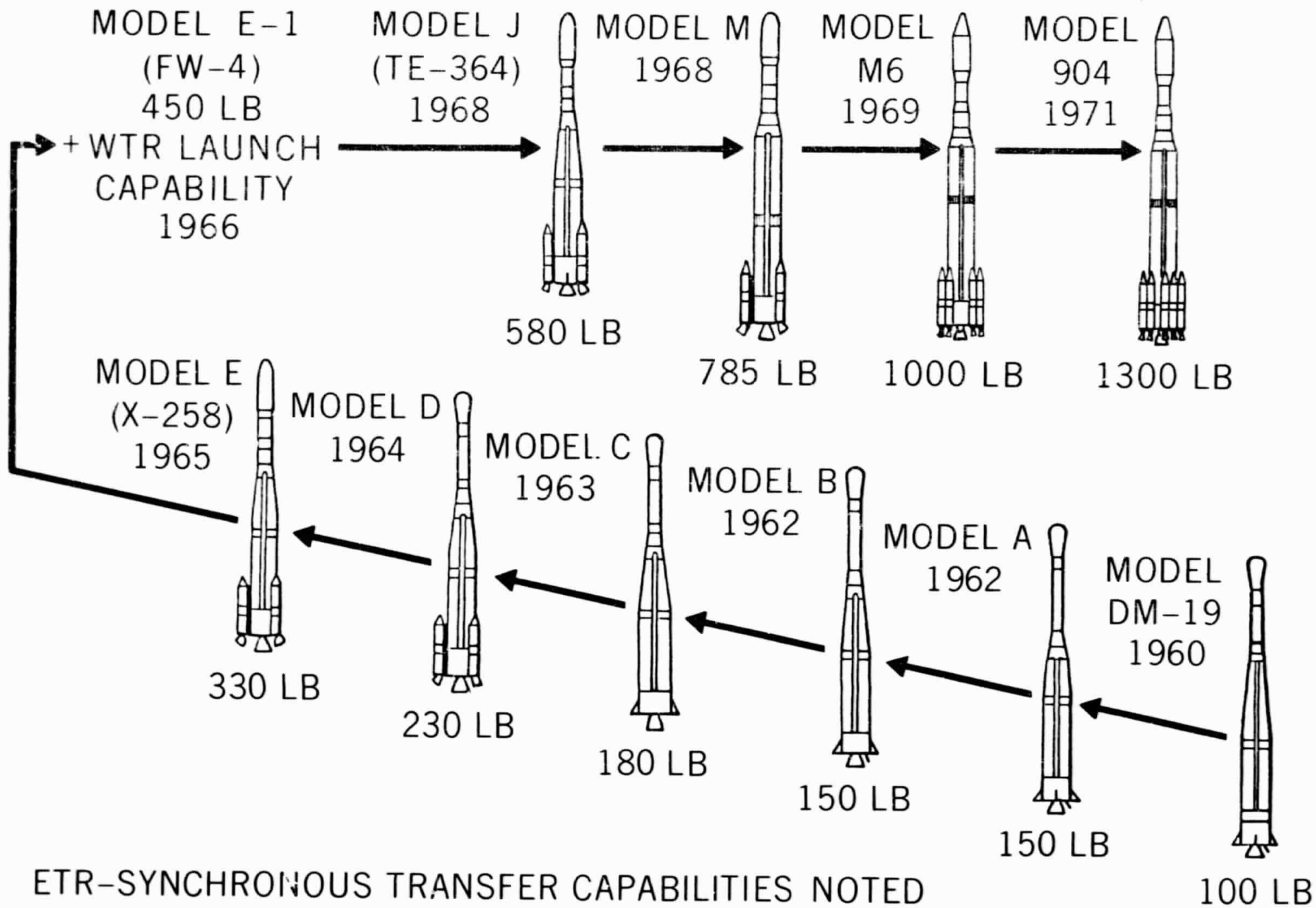


Figure 1. Delta Evolution

synchronous communications satellite. The second TAD vehicle orbited the first commercial communications satellite, Comsat Corporation's Early Bird Satellite (April 1965).

Another order of Deltas in 1964 brought the development of the Improved Delta (Model E). The Improved Delta model adapted and extended the large diameter propellant tanks from the Able-Star stage, and thereby nearly doubled the propellant capacity of the previous Delta second stage. The larger diameter tanks in addition permitted adaption of the five foot diameter Nimbus fairing developed for the USAF Agena stage. Improved Delta also adapted the USAF developed FW-4 solid propellant motor to replace the X-258 third stage motor (Model E1). The first Improved Delta was launched November 1965 and among the missions carried on this model of Delta are the near polar Geophysical Orbiting Satellites, GEOS A and B; the heliocentric Pioneer series A through D; the low earth orbiting Biological Satellite, BIOS A through C; the synchronous communications satellites, Intelsat F1 through F4; the lunar orbiting Anchored Interplanetary Monitoring Probe, A-IMP A and B; the sun-synchronous ESSA 2 through 6; the High Eccentric Orbiting Satellite, HEOS developed by the European Space Research Organization and the Canadian International Satellite for Ionospheric Studies, ISIS.

In 1966 Delta undertook to adapt the Surveyor spacecraft solid propellant retromotor as a new third stage. The spherical case was modified to mate to a spin-table assembly and the motor, designated TE-364-3, was requalified for the Delta spinning environment. The first Delta using this third stage motor, Delta Model J, was launched in July 1968 and carried the Radio Explorer, RAE-A spacecraft.

At about the same time Delta initiated the adaption of the TE-364-3 motor, the USAF undertook the uprating of the Thor booster by lengthening the liquid oxygen and RP-1 fuel tanks and converting the fuel tank to a constant 8 foot diameter. This Long Tank Thor carries about 47 percent more propellants than previous models. In September 1968, Delta launched its first Long Tank Thor with the Improved Delta second stage and TE-364-3 third stage. The Delta Model M carries, among others, the Intelsat III series and the British Skynet and NATO communications satellites.

In early 1968, Delta started a redesign of the Long Tank Thor engine section to permit the addition of a second set of three thrust augmentation solid motors. The first Delta Model M6 with six solid motors is to be launched from the Western Test Range late this year and carry the NASA TIROS Operational Satellite, TOS-M into a 800 n. mi. circular sun-synchronous orbit. The Delta Model M6 is to be used also to carry the Interplanetary Monitoring Probe I, the RAE-B, and European Space Research Organization TD-1 spacecraft.

To date, Delta is launching over fifty percent of NASA's unmanned spacecrafts each year and has been selected for the use of private industry and foreign governments. The reliability and cost effective history of Delta is, in a large part, attributable to the technical approach taken at the outset of the program and still adhered to today. This approach is to use current technology and flight proven components wherever possible from other space programs. The resultant vehicle is normally heavy, but cheap and has a high probability of performing repeatedly and reliably from the outset. Delta has never considered it necessary to have a pre-operational or development flight test launch for any of the ten major changes made to the vehicle. And with the exception of the first Delta launch in 1960, there has never been a failure of the first flight article on its maiden launch. The criteria for evaluating improvements to Delta is that they must meet the mission requirements at the lowest possible cost and risk without compromise of Delta's reliability record—currently 66 successes out of 73 launches. For this reason Delta has wherever possible, adapted flight proven components from other programs. The next evolutionary uprating of Delta is consistent with this past pattern of change.

II. THE DELTA LAUNCH VEHICLE

To keep pace with the growing launch capability requirements of scientific and applications satellites, both domestic and foreign, the Delta launch vehicle is being uprated in performance capability, in guidance accuracy, and modernized to enchance overall systems reliability. This new Delta with nine strap-on solid motors (Model 904) is shown in Figure 2 and is composed of the Long Tank Thor, now with an option of thrust augmentation from combinations of 3 to 9 strap-on solid motors; the Delta second stage converted to higher energy storable propellants with the substitution of the Aerojet Titan Transtage ablative engine for the current Vanguard/Able-Star vintage regenerative engine, an on-board strap-down inertial measurement unit and general purpose navigation computer in the second stage to replace the first and second stage autopilots and the Western Electric Company (WECO) radio-guidance system; and the Thiokol TE-364-4 solid propellant third stage motor. This Delta is described together with its performance, flight environment, spacecraft integration organization, milestones and operations and launch costs. The Delta Model 904 is now scheduled to launch the Planetary Explorer series, the Interplanetary Monitoring Probes J and K, and the Synchronous Meterological Satellites.

A. Vehicle Description

The three stage Delta vehicle Model 904 shown in Figure 2, stands 106 feet and weighs 261,000 pounds at lift-off. The vehicle is designed for ascent through

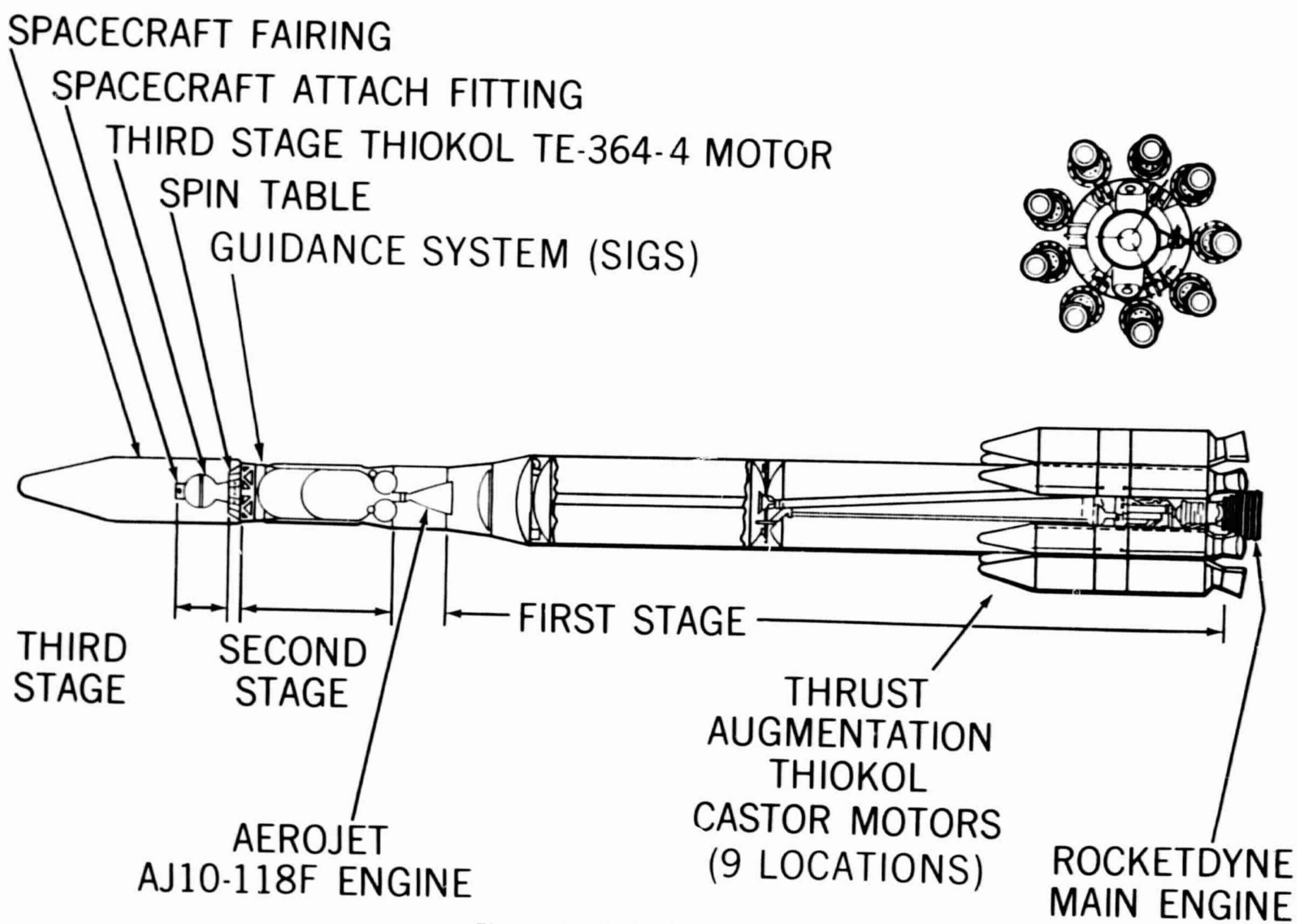


Figure 2. Delta (Model 904)

95% Eastern Test Range (ETR) and Western Test Range (WTR) upper atmosphere annual wind profiles, lift-off in 40 knot ground winds, and hold on the launch pad for hours in readiness to meet a launch window only seconds wide.

The first stage liquid propellant core is the Long Tank Thor. The core is 8 feet in diameter, 60 feet long, carries 147,000 pounds of RP-1 and liquid oxygen propellants and is powered by a turbopump fed Rocketdyne main engine that develops 175,000 pounds thrust at lift-off. The core burns to propellant depletion about 220 seconds after lift-off (T+220) at an altitude of 60 to 70 nautical miles (n.mi.). Thrust augmentation solid propellant motors attach at the base of the first stage core to an universal boat-tail (UBT) engine section structure. The UBT is structurally designed and thermally insulated to carry up to 9 Thiokol Castor II solid motors (TX-354-5) or 3 Algol class of solid motors with 6 Castor II's. Use of the Algol class of solid motors is not approved at this time. The UBT uses the same solid motor attach and separation hardware as on all Thrust Augmented Thors. The new Ignition and Separation Sequence Unit developed to ignite and separate the solids after lift-off draws directly from the present unit. The simple, straight forward structural, plumbing and electrical modifications to the present engine section obviates the need for extensive testing or a pre-operational flight test.

Normally, the thrust augmentation motors are built-up in sets of 3. Up to 6 motors can be ignited on the pad and the remainder no sooner than 38 seconds after lift-off in order to hold the vehicle acceleration induced loads on the propellant tank bottoms within allowable limits. The Castors II motors each develop 33,000 pounds thrust at ignition, burn for 40 seconds and are jettisoned from the core in sets of three at five seconds intervals starting at T+85. This time is dictated by considerations of combined dynamic pressure angle-of-attack loadings on the jettison mechanism and a Range Safety requirement for an off-shore impact of the expended motors. Jettison is effected by firing and explosive bolt holding a clamped ball-socket joint. Acceleration of the core plus aerodynamic drag on the motors eject the cases away from the vehicle as shown in Figure 3.

During powered flight pitch and yaw steering is exerted by gimballing the core main engine. Roll control is effected by differentially gimballing a pair of small outboard vernier engines. Subsequent to main engine shut-down the verniers continue to operate for about 12 seconds, damping shut-down transient and stabilizing the vehicle for staging of the second stage.

Guidance and control of the first stage originates from a new strap-down inertial guidance system (SIGS) located in the second stage. An inertial measurement unit composed of an orthognal set of linear accelerometers and rate

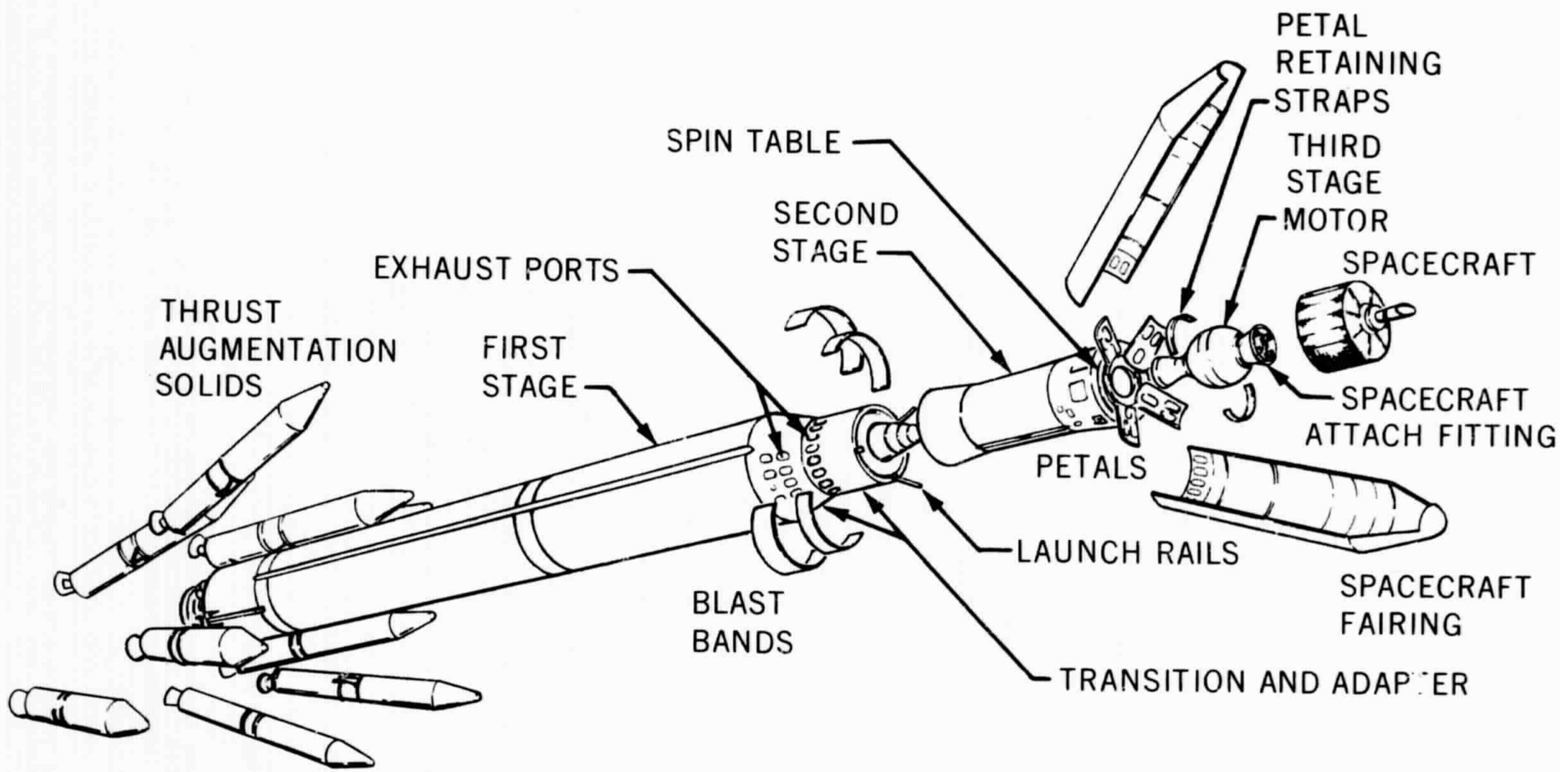


Figure 3. Delta Staging Schematic

integrating gyros sense vehicle linear and angular motion. An on-board general purpose storable program computer directs the vehicle through a pre-programmed trajectory, calculates the present position and velocity, then integrates the nominal trajectory forward to determine the position and velocity at injection. This state vector is then compared to the desired terminal condition to determine the required steering commands to reach the desired terminal injection point. This computer also performs the functions of commanding discreet flight functions as well as issuing pre-programmed command attitude rates during powered and coast guidance phase of flight. The new SIGS replaces two independent first and second stage autopilots on Delta and the associated Western Electric Company (WECO) ground radio-guidance system. With SIGS, the relatively expensive ground tracking station support costs are avoided and flight profile and attitude constraints together with horizon viewing limitations are eliminated. Thus, launch costs are reduced, the vehicle performance is increased and closed loop guidance is extended beyond the radio horizon with an attendant increase in injection accuracy. The introduction of SIGS also afford a modernization of the total Delta vehicle guidance and control system which today still utilizes vacuum tubes, punched tape mechanical programmers, mechanical rotary inverters, and solder type electrical connectors.

The interstage section between the first and second stages is provided with exhaust and access ports to allow the escape of exhaust gases during second stage engine start in the interstage. These ports are covered in flight with band assemblies that are jettisoned (Figure 3) at first stage main engine shut-down. Four seconds later explosive bolts that attach the two stages are fired and the second stage engine is started.

The Delta second stage is 17 feet long, approximately 5 feet in diameter and weighs 12,600 pounds at ignition. The Aerojet engine developed for Vanguard and adapted by Delta is now replaced by the flight proven Aerojet engine developed for the Titan III Transtage. This pressure fed ablative and radiation cooled engine develops 9460 pounds thrust at an uprated 125 pounds per square inch chamber pressure and operates for about 320 seconds on Aerozine-50 and N_2O_4 storable propellants. To adapt the engine to Delta the gimbal mount is redesigned to accept the Delta actuators and the radiation cooled nozzle extention is trimmed back to an area ratio of 26 to 1 from 40 to 1 to keep the same dimensional envelop for staging clearances.

The common bulkhead between the fuel and oxidizer tanks is shifted slightly aft to adjust to the new propellant mixture ratio and the helium pressurization regulator for the tanks is modified to reduce the pressures to match the engine requirements. Since the engine, designated AJ 10-118F for Delta use, is fed through a single bi-propellant valve the repeatability and reliability of the start

and stop sequence is considerably higher than the current Delta engine with independent pilot and main fed valves. Hence, the overall reliability of the second stage propulsion system is enhanced and at the same time the stage performance is boosted about 8 percent.

During the second powered flight, pitch and yaw steering is provided by gimballing the engine and roll is controlled by cold nitrogen gas jets. Cold nitrogen gas jets control the vehicle in all axes during coast and provides propellant settling ullage thrust for restarting the engine. The control system electrical power and nitrogen gas supply is capable of maintaining second stage attitude for a little over two hours. For long second stage coast periods before third stage spin-up and separation the second stage may be reoriented with respect to the sun or the vehicle placed in a slow yawing or pitching tumble to alleviate assymetric solar heating of the spacecraft.

Peripheral second stage systems include a "C" band tracking beacon, a PDM/FM/FM 45 x 20 telemetry system, dual command destruct receivers and associated power supplies. The command destruct receiver system is capable of both cutting-off the second stage engine or destroying an errant vehicle.

The third stage assembly consists of a spin-table, the Thiokol TE-364-4 solid propellant motor, spacecraft attach fitting, spacecraft and the spacecraft fairing. The spin-table shown in Figure 4 consists of a bearing support structure and a conical third stage motor pedestal truss that is divided into four petals hinged at the base and clamped to the equator of the third stage motor by a "V" band. The "V" band is held in tension by two explosive bolts that are fired two seconds after the motor and spacecraft are spun-up and the 15 second time delay squib that ignites the TE-364-4 motor is started. The released petals fly outward under centrifugal force, releasing the third stage from the spin table (Figure 3). At the same instant the second stage is backed away from the free spinning third stage by venting propellant residual pressurant (helium) overboard through two retrojets. Approximately thirteen seconds later the third stage motor is ignited by the time delay squib. The TE-364-4 motor is essentially identical to the -3 model previously used except that a 14 inch cylindrical section is added between the two hemispherical halves of the case. The propellant weight is increased to 2350 pounds from 1440 pounds, it burns for 44 seconds and develops an average thrust of 15,000 pounds.

Torque to the spin table is imparted by combinations of small solid propellant rocket motors, which provide spin rates from 30 to 100 rpm (±10 percent) for spacecraft roll moment of inertia ranging from 20 to 170 slug-feet squared. A lower limit of approximately 30 rpm is dictated by minimum dynamic stability of the third stage/spacecraft assembly during third stage motor burning. If less

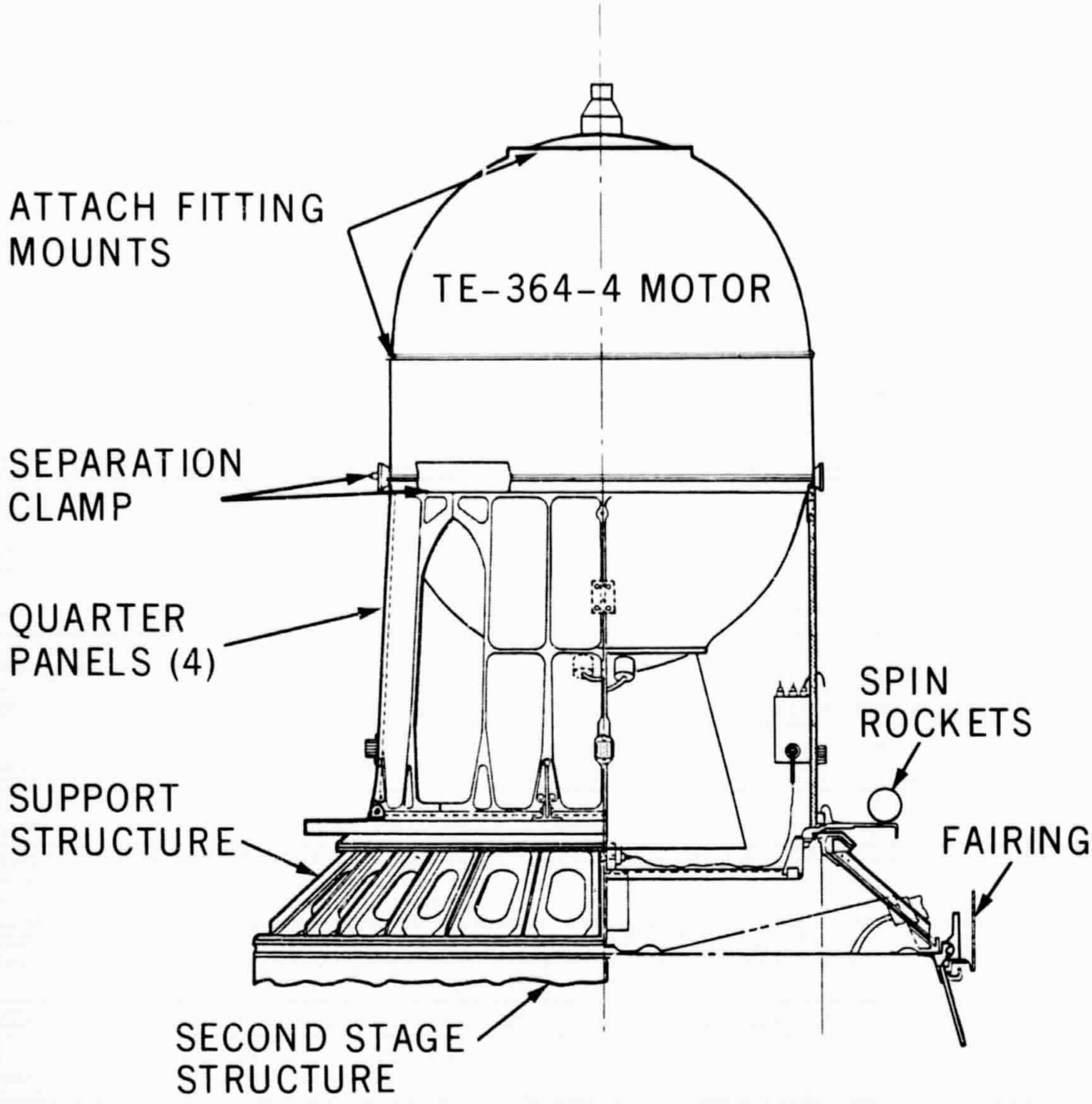


Figure 4. TE 364-4 Third Stage and Spintable

than 30 rpm is desired the effect upon orbit injection errors must be carefully assessed. The anticipated maximum spin rate users would desire was 100 rpm, consequently the third stage motor is qualified only up to this spin rate.

The spacecraft is clamped to the attach fitting by a circular V-clamp-band assembly that releases by firing two explosive bolt cutters subsequent to third stage motor burn-out. Separation from the expended third stage is then effected by a separation spring, or springs, which provides the spacecraft with a relative separation velocity of 6 to 8 fps with respect to the expended third stage motor. Although peculiar spacecraft requirements may dictate the design of a special spacecraft attach fitting, a number of standard Delta fittings are avilable. These

are specified in Table I and shown in Figure 5. These fittings use either a small rocket or yo weight system to tumble the expended third stage motor after spacecraft separation to preclude possible motor outgassing from accelerating it into the spacecraft. Also available is a yo-yo weight despin system which can despin the third stage and spacecraft combination prior to spacecraft separation. Attach fittings include timer assemblies, battery and delay squib switches. The timers are initiated by the second stage computer and run on mechanical energy until reaching a predetermined time to fire the spacecraft separation clampband bolt cutters and a pair of squib switches. Two seconds later the squib switches initiate a small rocket or yo weight to tumble the expended third stage motor.

For users requiring real time third stage motor performance, environmental or velocity increment information an "S" band telemetry system and a "C" band tracking beacon are developed and flight proven. These are carried on either the spacecraft attach fitting or on the third stage motor as optional equipment.

The spacecraft fairing is fiberglass, and constructed in two-half-shells that are brought up around the spacecraft laterally and clamped together by three strap assemblies that are released in flight by explosive bolts. Spring cartridges thrust the half-shells laterally and pivots at the base of the fairing cause the shells to rotate rearwards and clear the vehicle (Figure 3). Normally, the fairing is jettisoned within 5 to 20 seconds after second stage start. Fairing jettison time is dictated by the free molecular heating rate that can be tolerated by the spacecraft. Normally, the heating rate is held below 0.1 BTU/Ft^2-sec. or about equivalent to the solar heating rate to the spacecraft. Aerodynamic heating of the fairing is controlled by application of ablative materials to hold the fairing internal temperature to below 450° F. This precludes any possibility of spacecraft contamination from outgassing of the fiberglass phenolic.

Access ports through the fairing are provided at the locations that meet the needs of the vehicle user. The available fairing internal envelop is shown in Figure 6.

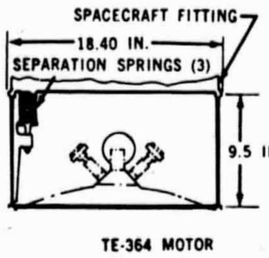
B. Flight Sequence and Performance

The Delta flight profile and sequence of events for a three stage synchronous transfer mission having a perigee altitude of 100 nautical miles (n.mi.) an apogee altitude of 19,400 n.mi. and an inclination of 28.5 degrees is shown in Figure 7. The vehicle is launched from ETR on an azimuth of 95 degrees. The pitch program consists of five discrete first stage pitch rates, two second stage rates, and a coast phase rate. The first and second stage have sufficient performance

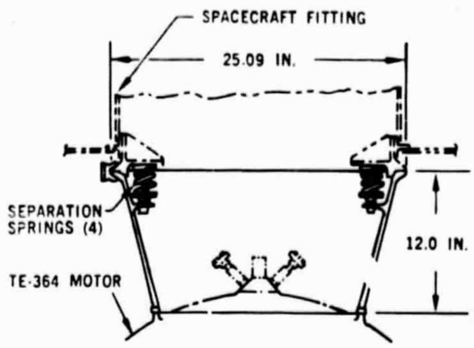
Table I
Delta Standard Attach Fittings

S/C INTERFACE DIAMETER, INCHES	HEIGHT INCHES	WEIGHT* POUNDS	FLT. QUALIFIED ON	COST THOUSAND DOLLARS
18	9.5	24	GEOS SERIES	$ 28
20	30	27	INTELSAT II SERIES	28
25	12	30	INTELSAT III SERIES	24
37	31	54	TIROS M SERIES	30

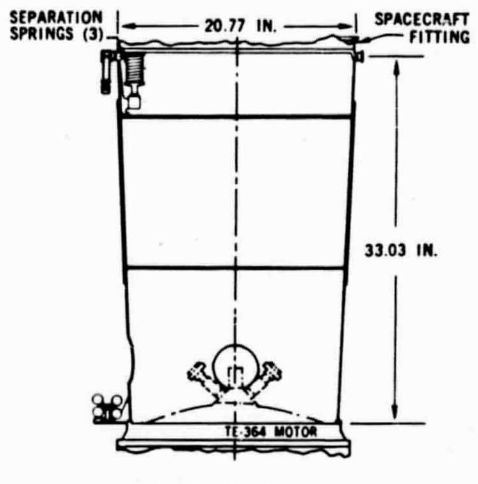
*INCLUDES ELECTRICAL SYSTEMS FOR SEPARATION AND TUMBLE



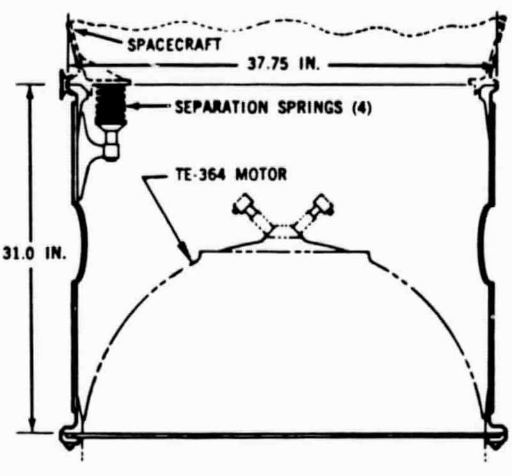
18 × 9 INCH CYLINDRICAL ATTACH FITTING
WT: 24 LB



25 × 12 INCH CONICAL ATTACH FITTING
WT: 30 LB



20 × 30 CONICAL ATTACH FITTING
WT: 24–30 LB



37 × 31 INCH CYLINDRICAL ATTACH FITTING
WT: 54 LB

Figure 5. Delta Payload Attach Fittings

to place the third stage assembly into a 100 n. mi. parking orbit. After second stage engine cut-off, the stage then coasts to a point just short of the Equator where third stage spin-up, separation and ignition occur. The third stage burns out directly over the Equator at an altitude of 100 n. mi., an inertial flight path angle of zero degrees, and with sufficient velocity to coast the spacecraft to an altitude of 19,400 n. mi. on the opposite side of the Earth so that the line of apsides lies in the equatorial plane to permit the spacecraft apogee motor to rotate the transfer orbital plane into the equatorial plane as part of the circularization manuever.

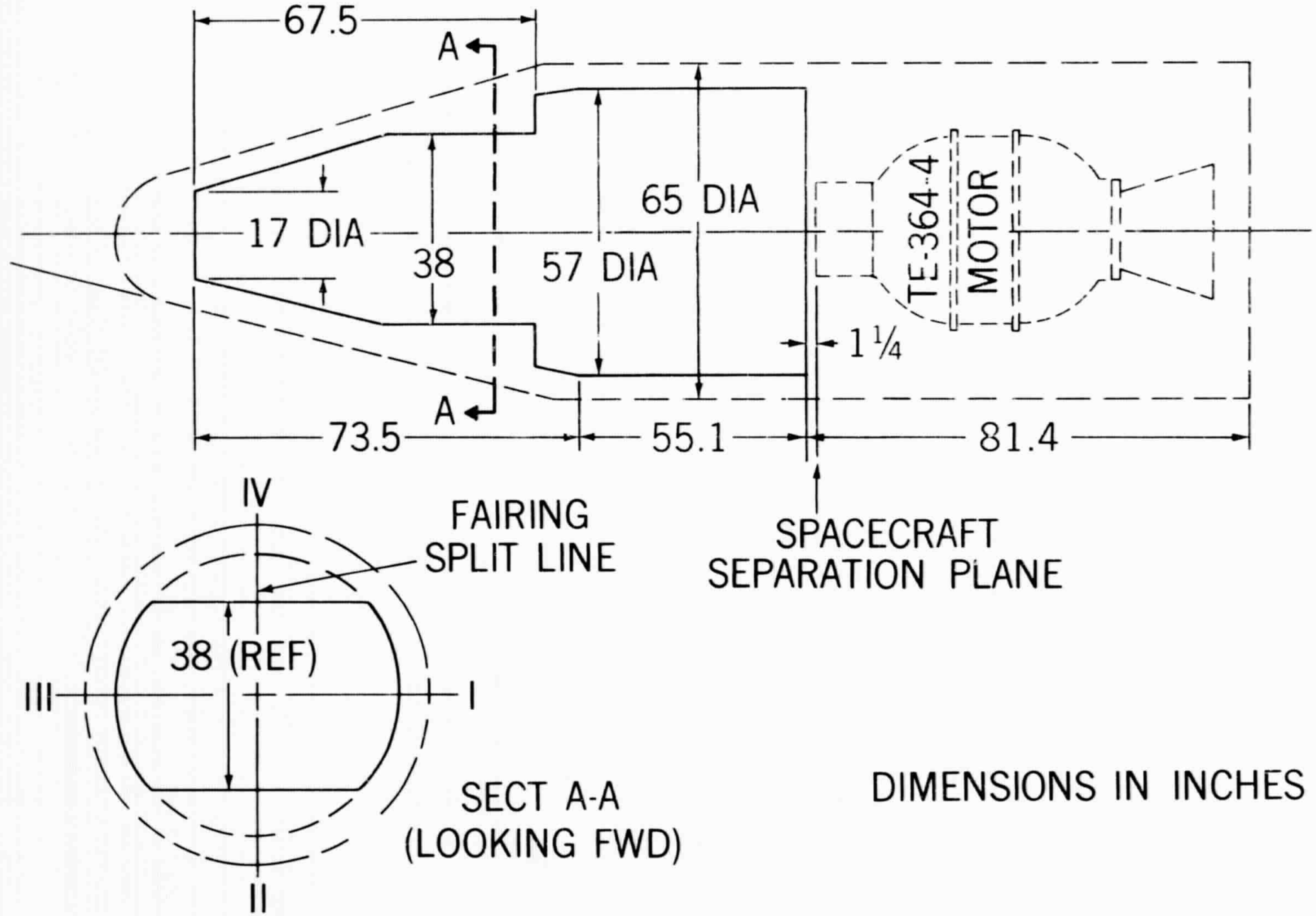


Figure 6. Delta Fairing Spacecraft Envelope

NO.	TIME (SEC)	EVENT	NO.	TIME (SEC)	EVENT
0	0	LIFT-OFF			
1	85	JETTISON SOLID MOTORS	5	552	SECOND STAGE CUT-OFF
2	218	FIRST STAGE BURNOUT	6	1443	THIRD STAGE IGNITION
3	222	SECOND STAGE IGNITION	7	1487	THIRD STAGE BURN-OUT
4	228	FAIRING JETTISON	8	1592	SPACECRAFT/THIRD STAGE SEPARATION

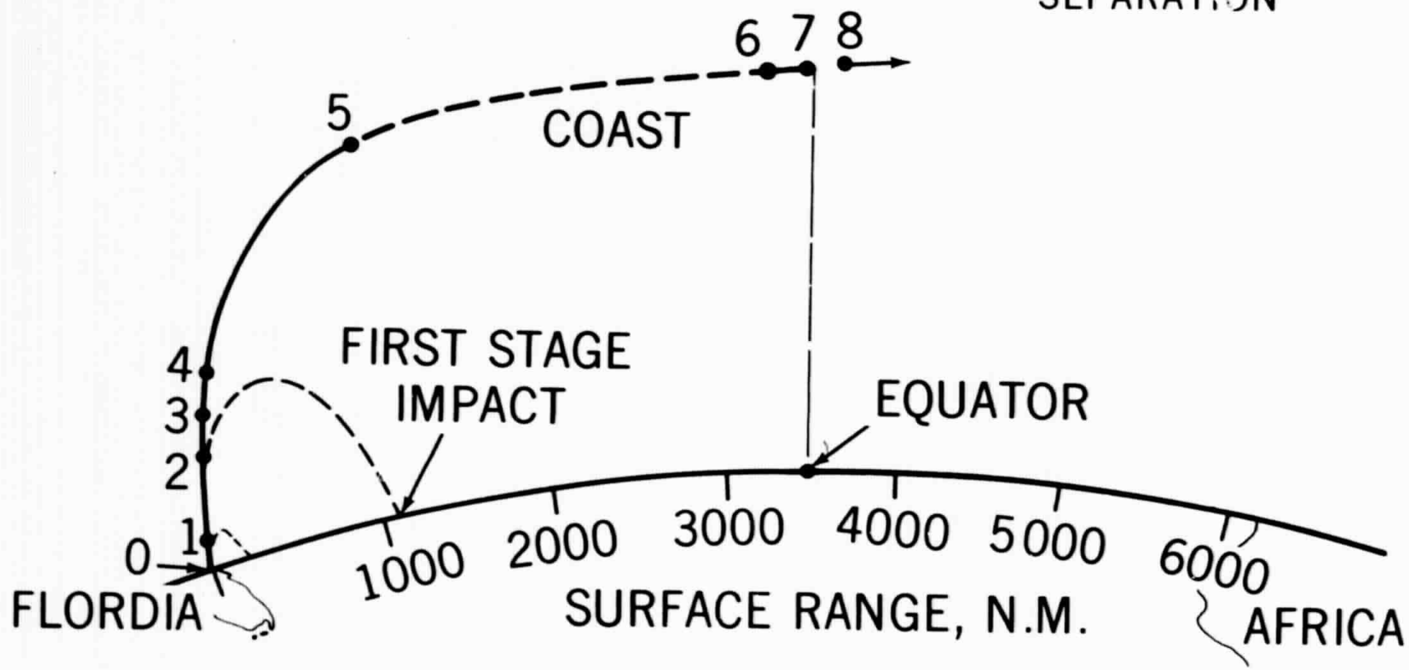


Figure 7. Delta Flight Sequence of Events for a Synchronous Transfer Mission

Payload weight versus characteristic inertial velocity for Delta from the Eastern Test Range in Florida and the Western Test Range in California is shown in Figure 8. The performance capability for a number of scientific and applications missions carried on Delta is summarized, in Table II. These Delta performance capabilities are the useful load that can be carried above the last powered stage and thus includes the spacecraft weight and its attach fitting hardware weight. The first number in the Delta model designation (3, 6, or 9) indicates the number of thrust augmentation solid motors, the second digit (0) the Delta second stage with SIGS and the AJ 10-118F engine, the third digit (4) notes the -4 version of the TE-364 third stage motor.

The injection accuracy of Delta is strongly dependent on the trajectory profile. The single largest injection error source is the unguided, spin-stabilized third stage. Nearly two thirds of the errors in injection velocity and attitude are caused by dispersions in the motor total impulse and lateral tip-off impulses applied during separation from the second stage and at motor ignition. Typically the 99 percent probability dispersions for a nominal 100 n. mi. by 19,400 n. mi. synchronous transfer trajectory is shown in Table III.

Though these dispersions are moderately large, it should be remembered that a synchronous communications satellite must carry a propulsion system for station keeping and hence the penalty paid in additional propellant to trim out injection errors is quite small.

The flight profile and sequences of events for a two stage (Delta; Model 90) sun synchronous 500 n. mi. circular orbit mission is shown in Figure 9. The vehicle is launched from WTR on an azimuth of 193 degrees. The second stage is injected into a 100 by 500 n. mi. Hohmann transfer and coasts 180 degrees to apogee where the second stage restarts and circularizes the orbit. The orbit dispersions for this type of mission is shown in Table IV for both the SIGS and the old autopilot/radio-guidance system that SIGS replaces.

C. Flight Environment

The spacecraft environment is estimated from previous flight measurements. A summary of the expected environment for both the two and three stage Delta vehicle is provided in Table V.

At lift-off the spacecraft is subjected to both lateral and longitudinal sinusodial vibration that load the spacecraft structure dynamically. At the time the three stage Delta lifts off the launch pins and the umbilicals are simultaneously retract at stations along the length of the vehicle, the spacecraft can experience a maximum of ±2.5 g, zero-to-peak (O-P), in the vehicle lateral modal frequencies (2 to 13 Hz). Superimposed at this time is a ±1.5 g (O-P) longitudinal

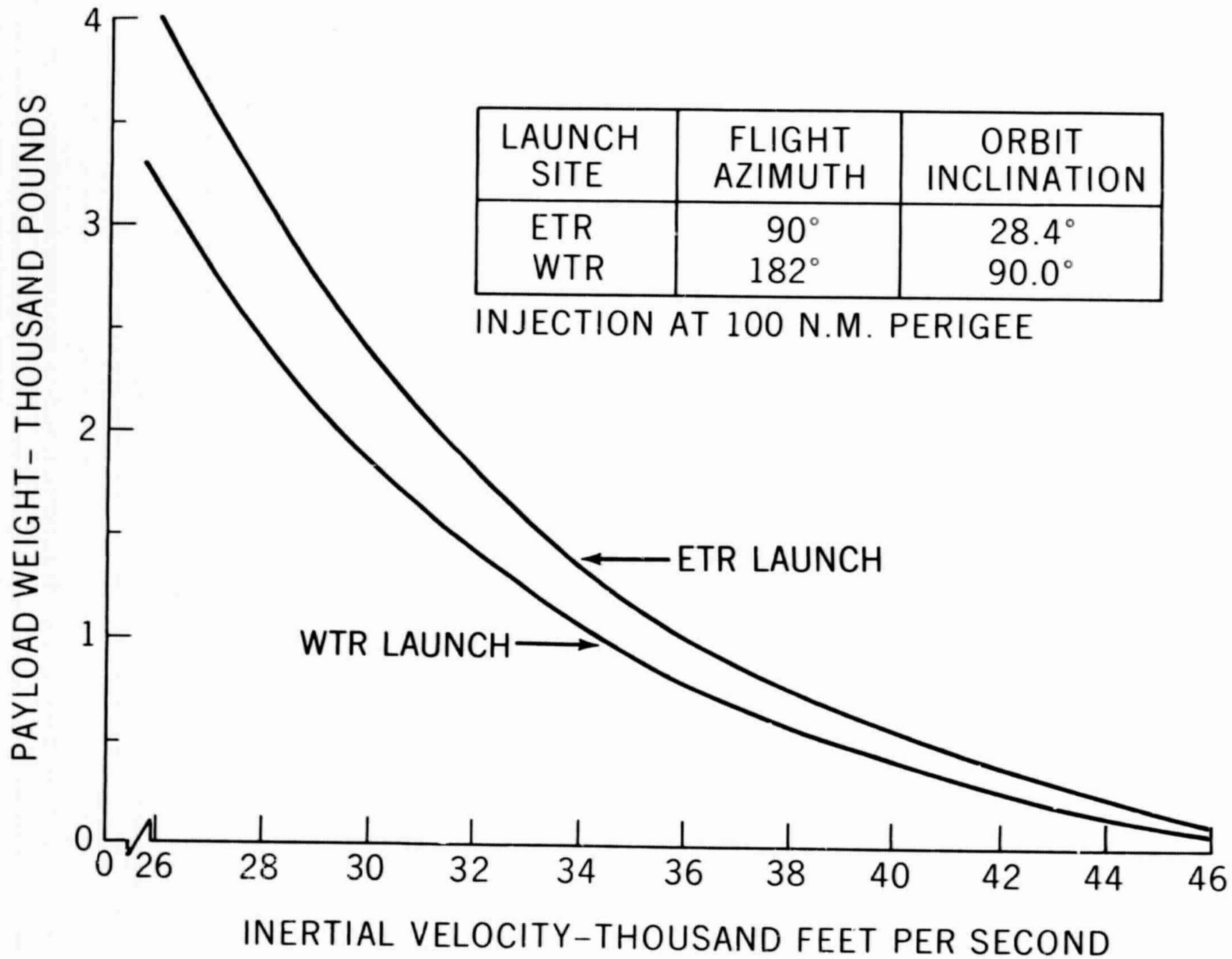


Figure 8. Characteristic Velocity for Delta Model 904

Table II
Delta Performance Capabilities

MISSIONS	FLIGHT MODE	DELTA PERFORMANCE CAPABILITY-POUNDS MODEL NUMBER		
		304	604	904
BIOSATELLITE 200 N.M. CIRCULAR INCL. = 28 DEGREES	TWO STAGE, RESTART 100 × 200 N.M. HOHMANN TRANSFER.	2800	3400	3700
EARTH RESOURCES 500 N.M. CIRCULAR SUN-SYNCHRONOUS INCL. = 99 DEGREES	TWO START, RESTART 100 × 500 N.M. HOHMANN TRANSFER.	1550	1950	2200
IMPROVED TIROS OPERATIONAL SATELLITE (ITOS) 800 N.M. CIRCULAR SUN-SYNCHRONOUS INCL. = 102 DEGREES	TWO STAGE, RESTART 100 × 800 N.M. HOHMANN TRANSFER.	1250	1550	1800
NATO-A SYNCH. TRANSFER 100 × 19,400 N.M. INCL. = 28.5 DEGREES	THREE STAGE. DIRECT ASCENT. SECOND STAGE PLACED IN 100 N.M. PARKING ORBIT.	1000	1200	1300
PLANETARY EXPLORER VENUS-TYPE II $C_3 = 8.231\ KM^2/SEC.^2$	THREE STAGE DIRECT ASCENT. SECOND STAGE PLACED IN 100 N.M. PARKING ORBIT.	625	725	800

13 cps oscillation. These combined lift-off oscillations typically last for two to five seconds with the peak acceleration lasting one to two cycles. During the last twenty seconds of first stage flight, the Thor exhibits a 20 Hz "pogo" longitudinal oscillation that builds up to ±4 g (O-P) at the time the steady stage longitudinal acceleration has reached about 6.3 g. The maximum first stage steady state acceleration of 8 g's is the highest imposed by the two stage Delta. For three stage Delta, the maximum steady state acceleration is dictated by the TE-364-4 third stage and reaches 23 g's for a 500 pound spacecraft or 10 g's for a 1500 pound spacecraft.

Table III
Synchronous Transfer Orbit Dispersions

PARAMETER	NOMINAL	99% PROBABLE DISPERSION
APOGEE ALTITUDE, N.M.	19,400	±900
PERIGEE ALTITUDE, N.M.	100	±30
ORBIT PERIOD, MINUTES	633	±31
ORBIT ECCENTRICITY	0.73	±0.01
ORBIT INCLINATION, DEGREES	28.5	±0.70

NO.	TIME (SEC)	EVENT
0	0	LIFTOFF
	85	JETTISON SOLID MOTORS
	218	FIRST STAGE BURNOUT
3	222	SECOND STAGE IGNITION
	228	FAIRING JETTISON
5	541	SECOND STAGE CUTOFF
6	702	BEGIN 180° PITCH
7	2502	ENDS 180° PITCH
8	3469	SECOND STAGE RESTART
9	3480	SECOND STAGE CUTOFF
	3510	SPACECRAFT SEPARATION

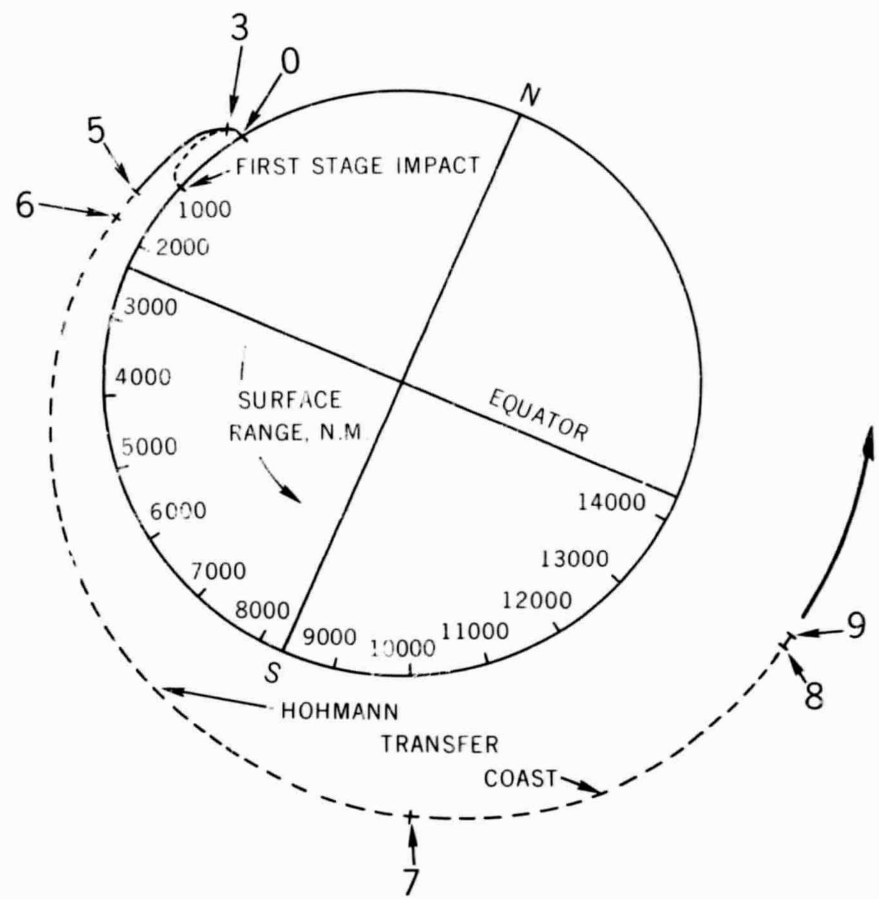


Figure 9. Delta Flight Sequence of Events for a Polar Circular Mission

Table IV
Sun-Synchronous Orbit Dispersions (Two Stage Vehicle)

PARAMETER	NOMINAL	99% PROBABLE DISPERSIONS	
		SIGS	RADIO-GUIDANCE
CIRCULAR ORBIT ALTITUDE, N.M.	500	±11	±25
ORBIT ECCENTRICITY	0	±0.001	±0.005
ORBIT INCLINATION, DEGREES	99.05	±0.03	±0.30
ORBIT PERIOD, MINUTES	103.27	±0.3	±0.4
PRECESSION RATE, DEGREES/DAY	0.986	±0.005	±0.045

Table V
Delta Critical Flight Environment

EXCITATION	FLIGHT EVENT	DURATION SECONDS	TWO STAGE		THREE STAGE	
			FREQUENCY, Hz	LEVEL	FREQUENCY, Hz	LEVEL
SINUSOIDAL VIBRATION THRUST AXIS	LIFT OFF	2 TO 5	10-17	1.5g (O-P)	10-17	1.5g (O-P)
	T + 210 SEC.	5 TO 7	17-23	3.5	17-23	4.0
			23-100	1.5	23-100	1.5
LATERAL AXIS	LIFT OFF	2 TO 5	5-100	1.0	5-14	2.5
					14-100	1.0
RANDOM VIBRATION THREE AXES	TRANSONIC & MAX. Q.	10 TO 15	20-300	+4db/OCTIVE	20-300	+3db/OCTIVE
			300-1000	$0.07g^2/Hz$	300-2000	$0.02g^2/Hz$
			1000-2000	-6db/OCTIVE		
SHOCK	SPACECRAFT SEPARATION	0.001	1600g AT 0.8 MILLISECONDS TERMINAL PEAK SAW TOOTH		1400g AT 0.3 MILLISECONDS TERMINAL PEAK SAW TOOTH	
STEADY STATE ACCELERATION	FIRST STAGE BURNOUT			8.0g		
	THIRD STAGE BURNOUT				23g FOR 500 LBS. SPACECRAFT 10g FOR 1500 LBS. SPACECRAFT	
ACOUSTIC	LIFT OFF AND TRANSONIC	10 TO 15	140db 37 TO 9600 Hz (PEAK LEVEL 800 TO 1000 Hz)			

Random vibration measured at the third stage attach fitting and spacecraft, show power spectrum densities between 0.001 and 0.02 g^2/Hz from 20 Hz to 2000 Hz in both lateral and longitudinal axes. The principle source of random acceleration is boundary layer turbulance over the fairing and the reverse slope of the second stage guidance compartment that excites the structure and feeds up through the third stage assembly to the base of the spacecraft. Acoustical excitation also contributes to the random levels experienced.

At lift-off and transonic, the overall acoustical level inside the fairing is approximately 140 db (referenced to 0.0002 dynes/cm^2) from 37.5 to 9600 cps. These levels are present for about 10 seconds at lift-off and again for about 15 seconds at transonic.

Shocks occur at main engine start, thrust augmentation solid motors ignition and jettison, staging, fairing jettison, and spacecraft separation from the expended third stage. For three stage Delta, cutting the bolts to separate the spacecraft from the expended third stage imposes the most severe shock spectrum on the spacecraft. The third stage motor and spin table assembly act to absorb the high frequency excitation from other sources. Cutting the separation bolts results in an estimated shock spectrum equivalent to a one-third millisecond, 1400 g terminal peak sawtooth input.

D. Organization and Interfaces

Delta users interface organizationally with three elements within NASA. This is best illustrated by the relationship that existed between the European Space Research Organization's, Project HEOS, and the NASA Delta Project and is shown in Figure 10. Agreement between NASA and a foreign space organization for a launch and associated services is established at NASA Headquarters level. This is normally done with a Memorandum of Understanding outlining the principles under which such arrangements are to be made, followed by a specific contract for each mission. The agreed-to policies and fiscal arrangements are then passed through the NASA Office of Space Sciences and Applications (OSSA) Delta Programs Office to the Goddard Space Flight Center (GSFC) Delta Project Office for implementation. The Delta Project Office is vested with the authority and responsibility for carrying out all aspects of a Delta vehicle mission. The Delta Project works directly with the Spacecraft Project to develop and define the spacecraft/vehicle mission requirements, integrate the spacecraft to the vehicle, establish schedules, and determine the final flight readiness of the vehicle. The Delta Project contracts with and directs a single industrial contractor, McDonnell Douglas Astronautics Corporation (MDAC) for the vehicle hardware, mission analysis, and launch support services. Direction of the launch support services furnished by MDAC at the launch site is delegated to the

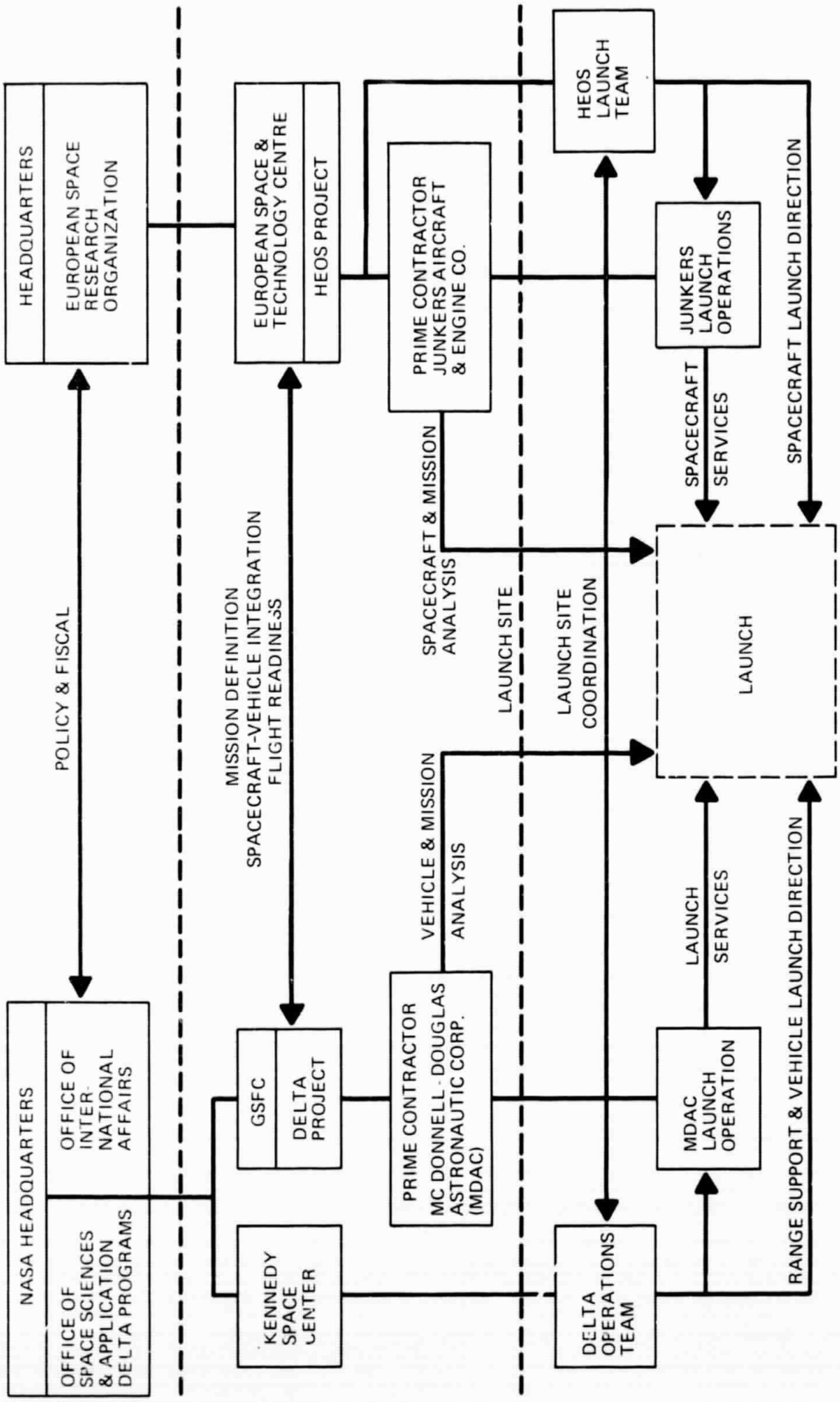


Figure 10. Organization and Interfaces

NASA Kennedy Space Center (KSC). The KSC Delta Operations Team works directly with the Spacecraft Project at the launch site to insure required Range and contractor services are provided and to coordinate the launch site vehicle and spacecraft activities.

This simple organizational structure with short and direct authority and communications lines is a significant factor in the flexibility and responsiveness Delta provides its users.

E. Spacecraft Integration and Launch Operation

Delta vehicle interface constraints together with performance and accuracy estimates are provided to potential vehicle users as soon as the concept of the mission is outlined to the NASA, Goddard Space Flight Center (GSFC) Delta Project Office. The Delta Project welcomes and encourages early definition of prospective missions by potential users. In some instances, mission definition and integration planning has preceded actual mission commitment by two and three years. Experience has demonstrated that this advance and continuous coordination between the user and the Delta Project during the period of developing mission requirements, enhances the visibility of both parties and reveals problem areas before final definition of the spacecraft/vehicle interface and trajectory parameters. In general, spacecraft/vehicle planning for new missions follow the pattern and time frame outlined in Figure 11 and starts about one year (T-52 weeks) before launch when the Spacecraft Project provides the Preliminary Mission Definition and Requirements to the Delta Project Office. This definition encompasses the preliminary spacecraft configuration, mass properties, trajectory, and orbital requirements necessary for preliminary vehicle performance evaluation and analysis. A preliminary trajectory with attendant injection error studies and thermal studies is completed within ten weeks. With this visibility, the Delta Project and the Spacecraft Project jointly develop a Final Mission Requirement specification (T-40 to T-26 weeks) that includes such constraints as spacecraft orbital lifetime, apogee and perigee altitude and geocentric location, permissible injection errors, injection attitude orientation, launch window criteria, tracking and data retrieval requirements, spacecraft mass properties, and all other data necessary for the preparation of the Final Mission Analysis.

The Spacecraft Project reviews the final mission trajectory about T-35 weeks and the final injection and orbital error analysis about T-23 weeks. The trajectory includes all technical data defining the flight mode, sequence of flight events, vehicle weights and propulsion system characteristics, tabulations of trajectory parameters, weight history, radar look angles, and instantaneous impact loci. Final definition of the maximum and minimum allowable spin rate, spacecraft RF systems, and permissible inflight thermal inputs are provided to Delta by T-26 weeks. A full scale compatibility drawing based on the Spacecraft

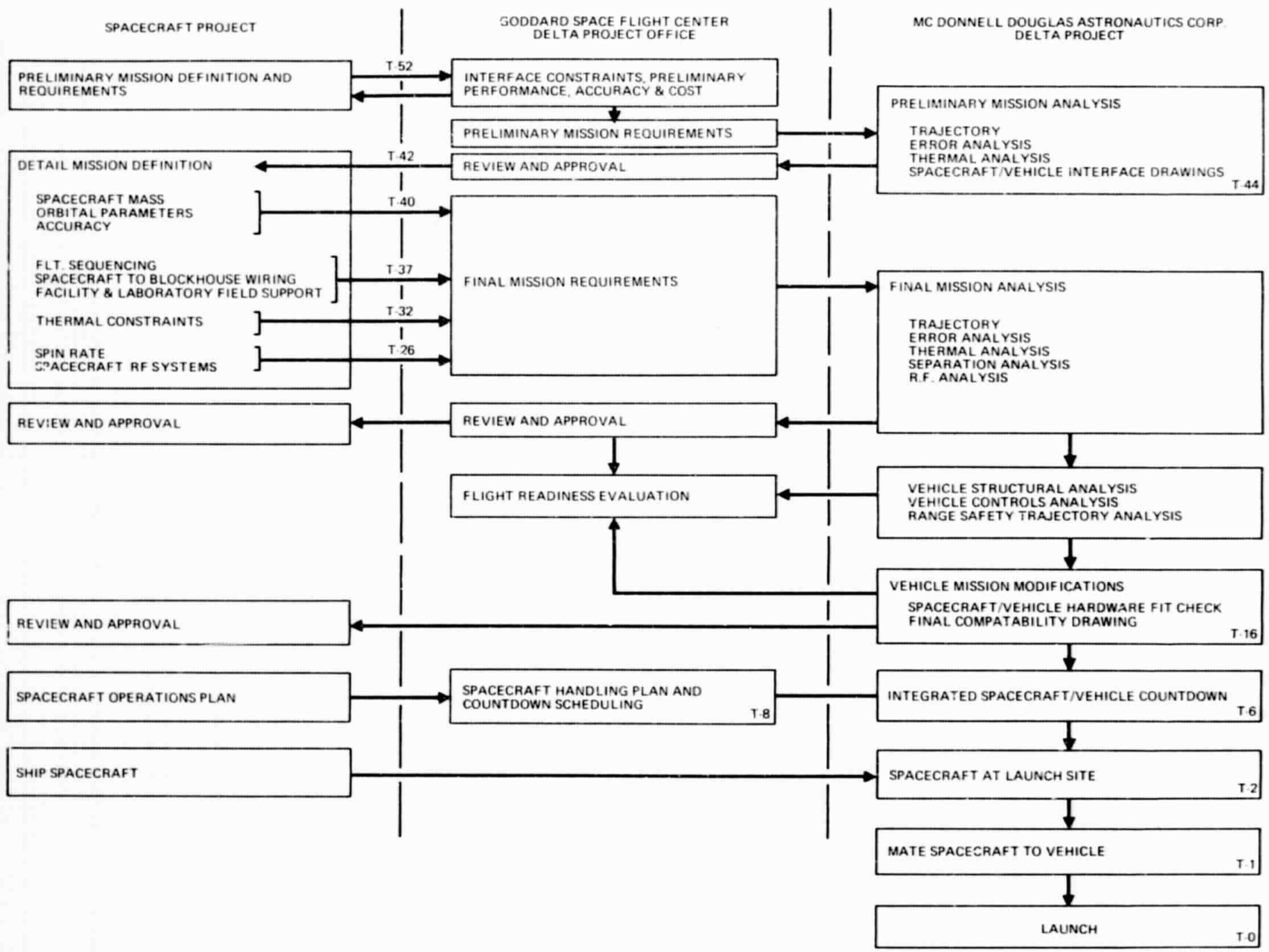


Figure 11. Delta Mission Analysis and Integration

Project's final configuration drawings is prepared normally at T-16 weeks. This drawing is primarily to show all clearances between the spacecraft and fairing, attach fitting, and third stage motor and locate the orientation of such features as umbilical connectors, access ports through the fairing, and any special interface wiring between the attach fitting and spacecraft. A Spacecraft Handling Plan is jointly developed and finalized about T-8 weeks and describes all hazardous systems, spacecraft test procedures, and details pre-launch work schedules. Typically the spacecraft arrives to the launch site two weeks before launch (T-2) and is built up on the third stage motor assembly the following week and mated to the vehicle on the pad one week before launch for RFI testing with the vehicle and Range RF systems. Final weights are inputed to trim the final trajectory parameters in the SIGS computer the week of launch.

The spacecraft must be statically and dynamically balanced prior to receipt at the launch site. The allowable spacecraft center-of-gravity offset and principle axis misalignment is 0.015 inches and 0.002 radians, respectively. For missions where injection attitude is extremely critical for mission success, a third stage assembly composite spin balance is conducted at the launch site.

Delta conducts launches from both ETR and WTR. Prograde missions with orbital inclinations of 30 degrees or less are normally launched from ETR and near-polar or retro-grade missions from WTR, though near polar missions have been launched from ETR.

Facilities for the Spacecraft Project use at the launch site include spacecraft assembly and checkout laboratories, telemetry, fabrication and cryogenic laboratories, clean rooms, shops, storage, and offices.

The first and second stage mission modifications to the vehicle are made in the MDAC production area in Santa Monica. Before shipment to the launch site, the stages undergo individual and then composite all-systems checkout, exclusive of the third stage assembly. The first and second stages are delivered directly to the launch pad, erected, and again undergo systems testing. The thrust augmentation solid motors and third stage solid motors are stored and prepared at the launch site. The thrust augmentation solid motors are mated to the first stage on the launch pad about two weeks before launch. The third stage motor is built up on the spin table and the spacecraft mated with the assembly at about the same time. The spacecraft/third stage assembly is transported in an environmentally controlled canister to an environmental room on top of the mobile services tower around the vehicle and there the assembly is mated to the vehicle. While the spacecraft is mated to the vehicle, spacecraft and vehicle checkout and testing is interspersed and whenever possible to accommodate the spacecraft requirements.

On pad checkout of the vehicle culminates in a pre-countdown simulated flight without propellant on-board, wherein all systems of the vehicle are exercised as they are during the mission. The simulated flight test takes place one week before launch and is followed by final preparation of the vehicle for launch and then a three day countdown to lift-off. If necessary, complete access to the spacecraft can be provided up to four hours prior to lift-off, though normally the fairing is installed about 12 to 16 hours prior to launch. Provisions to continuously power and monitor the spacecraft from the blockhouse is provided through the vehicle wiring. While the spacecraft is on the vehicle, thermally and hermetically conditioned, filtered air is provided to the spacecraft right up to lift-off.

Launches off the same pad at ETR have been conducted at two week intervals, though four weeks is a normal one-shift per day operation. For follow-on spacecraft in a mission series a called-up launch can be made on 90 days notice at no increase in launch costs provided it is an identical mission, the mission peculiar hardware (attach fitting, etc.) have been provisioned and the launch does not impact another scheduled mission. Call-up time may be reduced to 60 days at a cost of about $100,000 for factory and launch checkout overtime or to 30 days, provided the vehicle has been previously configured for the mission and completed factory checkout in anticipation of call-up. The 30 day option, however, requires commitment of about $175,000 of non-recoverable funds if call-up is not exercised. Delta has already launched two call-up missions in 1969. Although the normal call-up notice requirement was 90 days, these missions were accommodated in 60 and 21 days, respectively. Based on 9 years of experience at ETR, the probability of launching in a window 15 seconds wide on a given day is 69 percent. The probability for a thirty minute launch window, typical for most missions, is 86 percent. Recently, when spacecraft development delays impacted a number of Delta launches of lower priority and a call-up launch option was suddenly exercised, the Delta Project launched three spacecraft at one-week intervals to relieve a congestion of six spacecraft awaiting launch. Normally, however, the scheduled launch date desired by the Spacecraft Project can be met.

F. Cost

The projected cost of Delta Model 904 reimbursable launches in 1971 from ETR is about $5.0 million dollars. This includes hardware, trajectory software, spacecraft integration, launch support services, and NASA administrative charges. This cost does not include, however, charges made by the U.S. Air Force for Range use that would include tracking, data acquisition, technical operations and U.S. Air Force support charges as these costs are highly dependent on mission requirements. A breakdown of costs are provided in Table VI

Table VI
Delta Launch Costs (1971)

	COSTS (THOUSAND DOLLARS)	
	INITIAL LAUNCH	FOLLOW-ON LAUNCH
HARDWARE		
FIRST STAGE CORE	$900	$900
THRUST AUGMENTATIVE SOLID MOTORS (9)	700	700
SECOND STAGE AND FAIRING	1,200	1,200
THIRD STAGE	120	120
ATTACH FITTING	30	30
LAUNCH SERVICES		
SOFTWARE	700	500
VEHICLE CHECKOUT		
PRODUCTION AREA	200	200
LAUNCH SITE	800	700
RANGE LAUNCH SUPPORT	*	*
TRANSPORTATION	15	15
PROPELLANT	30	30
NASA ADMINISTRATIVE CHARGES	150	150
TOTAL	$4,845	$4,545

*RANGE TRACKING, DATA ACQUISITION, TECHNICAL OPERATION AND U.S. AIR FORCE SUPPORT CHANGES DEPENDENT ON MISSION REQUIREMENTS.

and are based on actual or estimated expenses billed to outside agency users such as ESSA, Comsat, and ESRO for reimbursement to NASA and a projection of these costs into the 1971 time frame when the Delta, Model 904 shall be available for launch. Actual charges for any given mission will, of course, vary to reflect the specific mission requirements.

For launches conducted for outside government agencies and private industry, identifiable launch service charges are segregated and charged directly against the mission. Indirect or cost not identifiable to a peculiar mission are prorated normally over the duration of a launch services contract or a number of Delta launches and allocated accordingly.

Since the first Delta launch in 1960, launch costs have increased from about \$2.5 million dollars to \$5.0 million dollars, while the performance capability into synchronous transfer orbit, for example, has increased from about 100 pounds to 1300 pounds. The net cost per pound in orbit then has decreased from \$25,000 to \$3,800 as shown in Figure 12. This cost effective pattern has been accomplished through ten major uprating in the Delta vehicle without a single development flight and in a period when materials and labor cost have more than doubled. Of primary importance to the user however, is this growth has been accompanied with a demonstrated flight reliability record of 90 percent. In establishing this figure, Delta also established a record of 22 consecutive successful space vehicle launches and again broke this record with another string of 25 successes.

In summary, the Delta, Model 904 that is to be available in mid 1971 will afford users greater performance and mission cost effectiveness together with greater orbit injection accuracy. This new model of Delta shall continue to meet the bulk of domestic and foreign government and industry needs and maintain the availability of a reliable, economical applications and scientific launch vehicle for future missions.

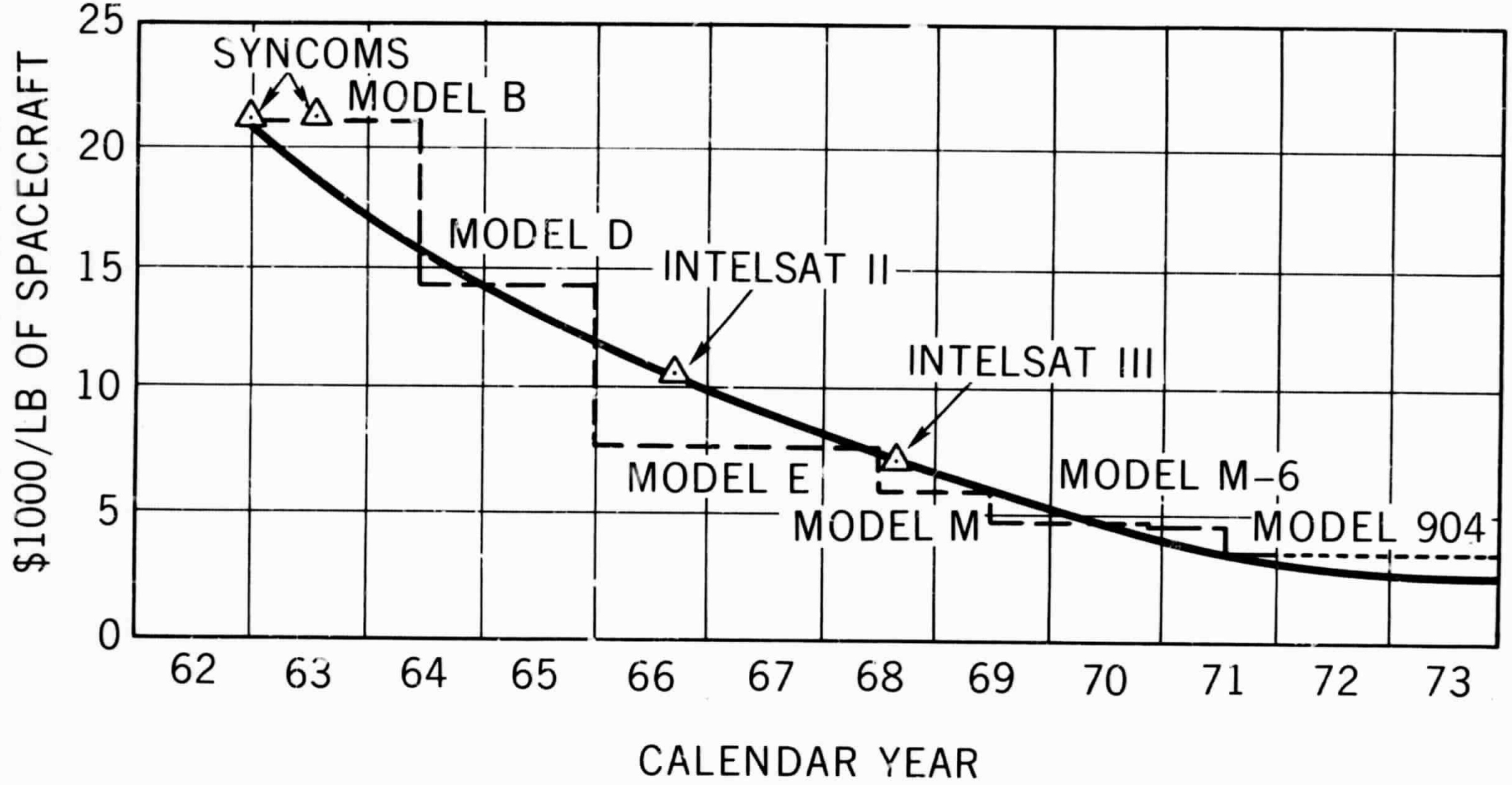


Figure 12. Delta Payload Cost per Pound Synchronous Transfer Mission — ETR